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Abstract Coral reef cryptofauna forms an important component of tropical marine biodiversity, consisting primarily of invertebrates dwelling in and on corals. During a survey carried out around the Semporna peninsula (Sabah, NE Borneo), the occurrence of gall crabs inhabiting mushroom corals was examined on reefs ranging from sheltered to exposed conditions. Out of 44 fungiid species, 19 were found to be associated with gall crabs. The gall crabs were observed at 85 % of the 62 studied sites, and their occurrence rates per site ranged between 0 and 25 %. High occupancy rates were almost equally distributed over the northern (sheltered) and southern (exposed) sites. Sites without gall crabs were all wave-exposed and predominantly under the influence of disturbances, such as blast fishing or relatively high nutrient loads.

Keywords Associated fauna · *Dacryomaia* · *Fungicola* · Sabah · Scleractinia · Species richness

Introduction

Coral reefs are well known for their high biodiversity. An important component of reef biota is formed by cryptofauna, predominantly consisting of endozoic and epizoic invertebrates associated with corals (Stella et al. 2011). Although reef corals are known to act as hosts to a wide range of invertebrates (e.g. Oigman-Pszczol and Creed 2006; Stella et al. 2010; Hoeksema et al. 2012), little information is available on environmental factors that affect the species composition of the associated fauna.

S. E. T. van der Meij (✉) · B. W. Hoeksema
Department of Marine Zoology, Naturalis Biodiversity Center, Darwinweg 2, 2333 CR, Leiden, The Netherlands
e-mail: sancia.vandermeij@naturalis.nl

Mushroom corals (Scleractinia: Fungiidae) are common Indo-Pacific reef corals. They have been used as a model taxon for a variety of studies, including research on regional and local biodiversity patterns (Hoeksema and Moka 1989; Hoeksema 1991a, 2007, 2012; Hoeksema and Koh 2009) as well as research on their associated fauna (Bos 2012; Hoeksema et al. 2012). Coral gall crabs (Brachyura: Cryptochiridae) are obligate associates of living stony corals, residing in galls or pits in their hosts. Their taxonomy has been revised (Kropp and Manning 1987; Kropp 1990), but many aspects of the distribution and ecology of the species have so far remained unknown (e.g. van der Meij 2012).

This study provides information on the occurrence of gall crab fauna in association with mushroom corals on reef assemblages in eastern Sabah, ranging from inshore sheltered conditions to exposed oceanic environments.

Materials and methods

Mushroom coral and gall crab data were collected during fieldwork on coral reefs in eastern Sabah (Malaysia) as part of the Semporna Marine Ecological Expedition in December 2010 (SMEE2010), using the roving diver technique (Hoeksema and Koh 2009). Data collection started around the deepest part of the reef (max. 30–40 m), and continued to the shallow part. For the identification of the host corals, a taxonomic revision of the Fungiidae (Hoeksema 1989) was used, combined with a classification based on a molecular phylogeny reconstruction (Gittenberger et al. 2011).

Fungiids were searched for gall crabs at 62 sites (Fig. 1), and the presence (or absence) of gall crab species was noted per mushroom coral host. The gall crabs were not identified to species level, as this would have required collecting all the gall crabs and their coral hosts, which was impossible in the given time frame. The gall crab–mushroom coral associations were taken from Hoeksema et al. (2012), and unpublished data (van der Meij et al., in preparation).

The gall crab occurrence rate per site was plotted on a map of the research area (Fig. 1; see also Waheed and Hoeksema: fig. 1). Multivariate analyses of the coral species composition were conducted for the survey sites using PRIMER 6 (Clarke and Gorley 2006). A resemblance matrix based on the Bray–Curtis similarity measure was used to determine the similarity between sites. Subsequently, a group-averaged cluster dendrogram was generated (Fig. 2), with the significant clusters derived by similarity profiles (SIMPROF). In addition, an MDS ordination of only the inhabited fungiid corals was performed. Lastly, a Pearson's chi-squared test was carried out to test for differences in the distribution patterns of the crab-inhabited fungiids between the more sheltered northern reefs and more exposed southern reefs.

Results

Occurrence rates

Out of 44 fungiid species recorded from the area (Waheed and Hoeksema 2013), 19 were found to be inhabited by at least a single gall crab (Table 1). The most frequently recorded fungiid hosts were *Lithophyllon repanda*, *Pleuractis granulosa*, and *P. paumotensis*. *Cycloseris vaughani* also showed a high occupancy rate, but this was based on low absolute numbers; only two specimens of this

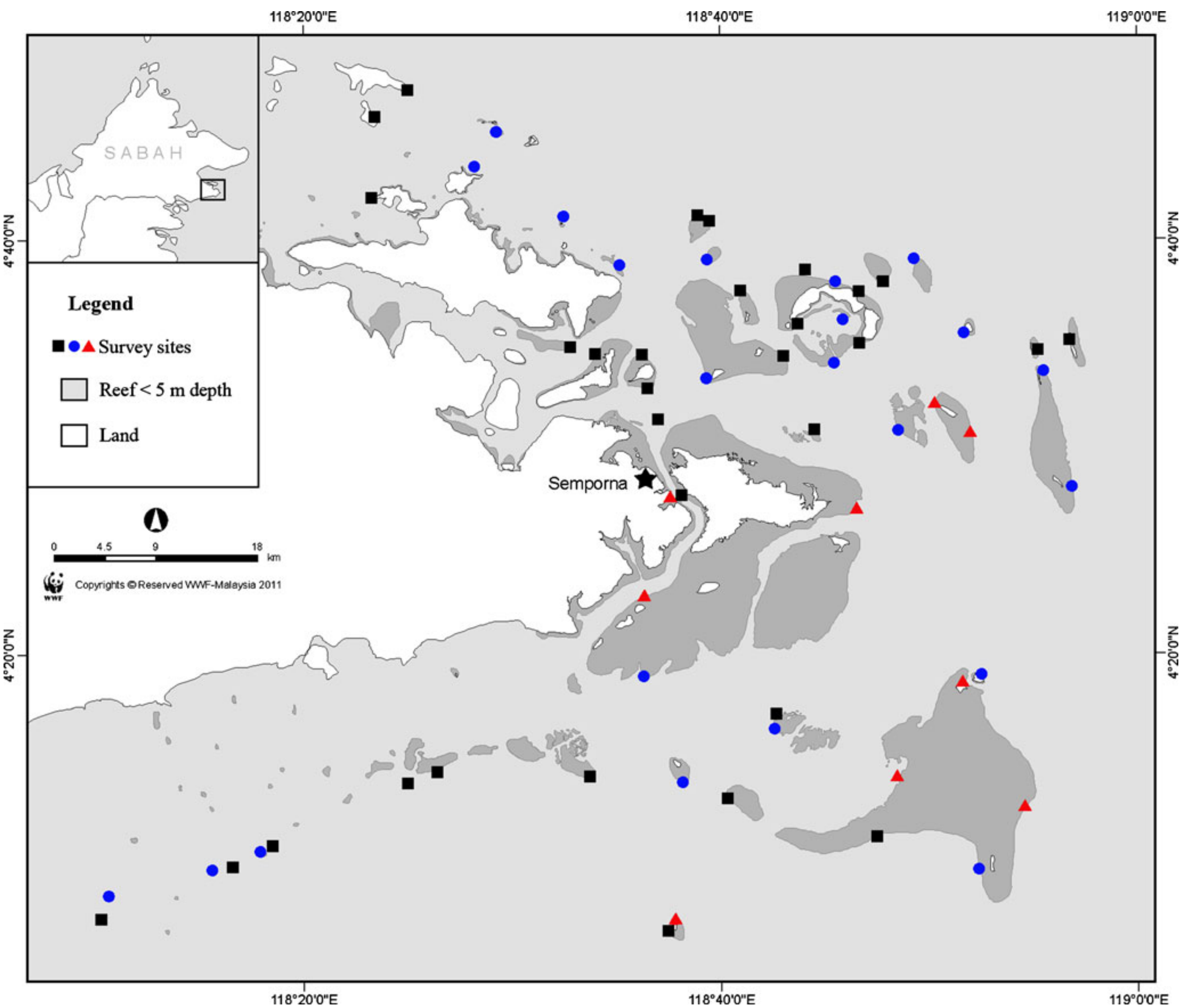

Fig. 1 Semporna, showing the various degrees of gall crab occurrence per site: *red triangles n*=0 %; *black squares* 0<*n*≤15 %; *blue circles n* >15 %. Percentages are based on the occurrence rates listed in Table 2

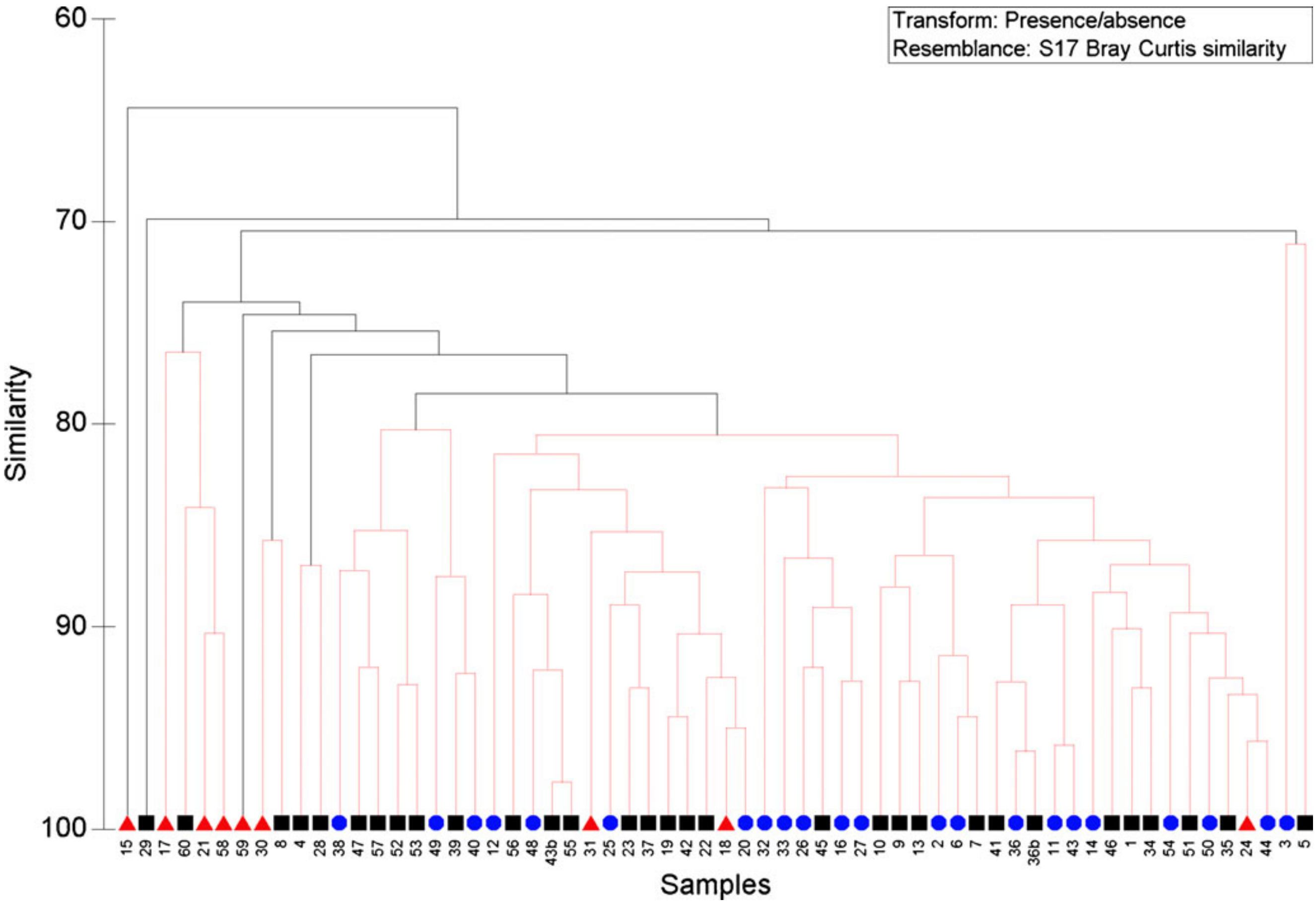

Fig. 2 The group-averaged hierarchical clustering of 62 sites, based on the species composition (presence/absence) of mushroom corals in Semporna. Significant clusters derived by SIMPROF are indicated by the *bold solid line*. The gall crab occurrence rates are indicated as follows: *red triangles* n=0 %; *black squares* 0<n≤15 %; *blue circles* n>15 %, see also Fig. 1

host species were found, one of which was inhabited. For five host species that were encountered on nearly all localities (61–62 out of 62), the number of sites with gall crabs differed considerably. Crabs inhabiting *P. paumotensis* were observed in 41 out of 62 localities, whereas gall crab in *Herpolitha limax* was observed only once (Table 1).

The occupancy rate ranged from 0 to 25 % inhabited host species per site. In general, sites with rates >15 % (Fig. 2) have relatively high numbers of recorded mushroom coral species. Seventeen of the 22 high gall crab occurrence sites had ≥20 recorded fungiid species (Table 2).

Distribution patterns

Gall crabs were observed at 85 % of the 62 studied reef sites, but the occurrence rates differed between the sheltered northern sites and the exposed southern ones. High host occupancy by gall crabs was almost equally distributed over the northern and southern sites, but sites without gall crabs were all located in the exposed southern area (Fig. 1). The reef sites richest in fungiid species were found in the northernmost part of the research area (Waheed and Hoeksema 2013: fig. 5), whilst the southern, more wind-exposed sites on average displayed lower numbers.

In a dendrogram showing clusters of localities based on the mushroom coral species composition (Q-mode clustering), nine significant clusters can be distinguished with three outliers. The majority of the sites grouped in one large cluster. After plotting the occurrence data on the dendrogram it becomes apparent that the outliers and the small clusters had the lowest gall crab occupancy (Fig. 2).

The MDS ordination of the inhabited fungiids (thus excluding the presence/absence data on non-inhabited fungiids) show no grouping based on locality.

Discussion

Occurrence rates

The results of the present study are difficult to compare with previous studies on gall crab occupancy rates,

Table 1 Overview of mushroom corals inhabited by gall crabs in the Semporna area *Hosts* No. of sites where fungiid is present, *Gall crabs* no. of sites where fungiid is inhabited by gall crabs, % percentage of sites where fungiid is gall crab-inhabited

Mushroom coral species acting as host	Hosts	Gall crabs	%
Pleuractis granulosa (Klunzinger, 1879)	62	30	48
Lithophyllon repanda (Dana, 1846)	62	26	42
Podabacia crustacea (Pallas, 1766)	62	13	21
Herpolitha limax (Esper, 1797)	62	1	2
Pleuractis paumotensis (Stutchbury, 1833)	61	41	67
Cycloseris costulata (Ortmann, 1889)	58	6	10
Sandalolitha robusta (Quelch, 1886)	58	5	9
Pleuractis gravis (Nemenzo, 1955)	53	1	2
Pleuractis moluccensis (van der Horst, 1919)	51	13	25
Lithophyllon scabra (Döderlein, 1901)	37	4	11
Cycloseris mokai (Hoeksema, 1989)	37	1	3
Cycloseris tenuis (Dana, 1846)	36	1	3
Lithophyllon undulatum Rehberg, 1892	15	4	27
Sandalolitha dentata Quelch, 1884	15	1	7
Lithophyllon ranjithi Ditlev, 2003	12	3	25
Lithophyllon spinifer (Claereboudt and Hoeksema, 1987)	7	2	29
Cycloseris somervillei (Gardiner, 1909)	4	1	25
Cycloseris hexagonalis (Milne Edwards and Haime, 1848)	3	1	33
Cycloseris vaughani (Boschma, 1923)	2	1	50

owing to different methods of data collection. In this study, occurrence rates per locality are compared, whereas in previous studies they were recorded per species. Three earlier studies used transects to determine the occurrence in various species of host corals. In the Red Sea, the gall crab *Cryptochirus coralliodytes* Heller, 1861 inhabited four faviid genera along transect lines (between 2 and 7 m) with 25 % infected hosts (Simon-Blecher and Achituv 1997), whereas at 10–20 m depth, 20 % of the individuals of the mushroom coral *Pleuractis granulosa* appeared to act as host for *Fungicola fagei* (Fize and Serène, 1956) (Kramarsky-Winter et al. 1995). A study in Brazil using belt transects showed that gall crabs infested 17–21 % of the host species *Mussismilia hispida* (Verril, 1902) and *Siderastrea stellata* Verril, 1868 (Oigman-Pszczol and Creed 2006). Another Brazilian study by Johnsson et al. (2006) recorded occurrence percentages for *S. stellata*, which ranged between 10 and 37 % depending on the survey site. In the Mexican Caribbean, Carricart-Ganivet et al. (2004) found that 21 % of *Manicina areolata* (Linnaeus, 1758) corals (n=160) were inhabited by *Troglocarcinus corallicola* Verrill, 1908. Lastly, in Vietnam, Fize and Serène (1957) encountered *F. fagei* in three out of 30 fungiids identified as *Parahalomitra* [= *Sandalolitha*] *robusta*, which most likely consisted of both *Sandalolitha dentata* (see Fize and Serène 1957: pl. XIII, DEF) and *S. robusta*.

Of the 31 recorded fungiid species that can act as gall crab hosts (Hoeksema et al. 2012), 30 were found in Semporna. Nineteen of these 31 were observed to be associated with gall crabs. *Cycloseris vaughani* is now recorded as a new host. Fungiids with the highest numbers of gall crabs are *Lithophyllon repanda*, *Pleuractis granulosa*, and *P. paumotensis*. *Cycloseris* species are not frequently observed inhabiting gall crabs, which may be restricted by the relatively small sizes of the hosts (see Hoeksema 1991b; Gittenberger et al. 2011). *Pleuractis granulosa* and *P. paumotensis* are hosts to the gall crab *Fungicola fagei*. In addition, *P. granulosa* is also known to be inhabited by *Dacryomaia* sp. *Lithophyllon repanda* is also associated with *F. fagei*, but is most frequently inhabited by *Fungicola utinomi* (Fize and Serène, 1956) (Hoeksema et al. 2012; van der Meij et al., in preparation). Molecular studies on gall crabs inhabiting Fungiidae indicate the presence of a cryptic species closely related to *F. fagei*, which is currently studied in more detail (van der Meij in preparation).

Herpolitha limax, host to both *F. fagei* and *F. utinomi*, occurred at all Semporna localities, but it was found only once to be inhabited by a gall crab. This mushroom coral can nevertheless be considered a hospitable species as it is host to a wide range of other associated organisms (Hoeksema et al. 2012). *Cycloseris* spp. that are hosts to *F. fagei* and *Dacryomaia* sp., were inhabited at only a few sites. These differences in occupancy rate indicate a host preference in certain gall crab species.

Table 2 Locality data of the sites visited during SMEE2010. *Hosts* No. of mushroom coral species, *Gall crabs* no. of gall crab-inhabited mushroom corals, % occurrence rate

Date	Site	Locality name	Latitude (N)	Longitude (E)	Hosts	Gall crabs	%
29 Nov	SEM.01	Roach reef, Mid rock/Tyre reef	04°10′39.0″	118°18′12.1″	22	2	9
	SEM.02	NW Roach reef, Second reef	04°10′31.5″	118°17′53.5″	17	3	18
30 Nov	SEM.03	SE of Tawau, Hand rock	04°08′24.5″	118°10′44.3″	28	6	21
	SEM.04	SE of Tawau, Darby rock	04°06′42.8″	118°13′39.7″	23	2	9
	SEM.05	SE of Tawau, Alert patches 2	04°09′38.5″	118°15′36.3″	17	1	6
	SEM.06	SE of Tawau, Alert patches 3	04°09′46.7″	118°16′35.8″	18	3	17
1 Dec	SEM.07	Erzherzog reef	04°14′26.5″	118°23′35.2″	18	2	11
	SEM.08	Horn reef	04°14′31.9″	118°26′25.0″	19	2	11
	SEM.09	Ligitan reef 1 S / Yoshi point	04°14′05.8″	118°33′26.7″	22	2	9
2 Dec	SEM.10	SE of Mabul Isl., Kapalai	04°13′05.4″	118°40′20.0″	17	1	6
	SEM.11	NE of Mabul Isl, W Cust reef	04°16′27.5″	118°42′32.9″	23	5	22
	SEM.12	Mabul Isl., Eel garden	04°13′49.8″	118°38′12.3″	22	4	18
3 Dec	SEM.13	Ligitan Isl., Ligitan 1	04°11′13.8″	118°47′27.9″	19	1	5
	SEM.14	Ligitan Isl., Ligitan 2	04°09′35.8″	118°52′22.2″	23	4	17
	SEM.15	Ligitan Isl., Ligitan 3	04°12′43.0″	118°54′36.6″	14	0	0
4 Dec	SEM.16	Si Amil Isl., Second beach	04°18′56.9″	118°52′33.8″	20	4	20
	SEM.17	W of Si Amil Isl., Denawan Isl.	04°18′55.9″	118°51′03.6″	15	0	0
	SEM.18	Ligitan Isl., Ligitan 4	04°14′06.5″	118°48′26.5″	20	0	0
5 Dec	SEM.19	Cust reef 2	04°17′08,3″	118°42′40.7″	17	2	12
	SEM.20	Creach reef	04°18′58.8″	118°36′17.3″	20	5	25
	SEM.21	Sipanggau Isl.	04°22′51.4″	118°36′20.3″	15	0	0
	SEM.22	Bumbun Isl. W (channel)	04°27′40.7″	118°38′09.1″	20	1	5
7 Dec	SEM.23	Pasalat reef	04°30′47.8″	118°44′07.8″	22	2	9
	SEM.24	Tg. Pantau Pantau, Bumbun Isl.	04°26′54.1″	118°46′31.0″	23	0	0
	SEM.25	Batura reef	04°30′48.6″	118°48′31.2″	19	4	21
8 Dec	SEM.26	Bohayen Isl.	04°28′00.9″	118°56′51.6″	24	4	17
	SEM.27	Timba Timba Isl.	04°33′37.7″	118°55′30.4″	21	4	19
	SEM.28	Pandanan Isl.	04°34′36.0″	118°55′14.1″	23	2	9
	SEM.29	Mataking Isl.	04°34′57.6″	118°56′46.5″	15	1	7
9 Dec	SEM.30	S Kulapuan Isl.	04°30′41.3″	118°51′58.4″	16	0	0
	SEM.31	N Kulapuan Isl.	04°32′09.6″	118°50′18.6″	21	0	0
	SEM.32	Pom Pom Isl.	04°35′29.8″	118°51′43.1″	17	4	24
	SEM.33	Kapikan reef	04°38′56.5″	118°49′15.0″	24	4	17
10 Dec	SEM.34	Mantabuan Isl.	04°37′56.0″	118°47′48.6″	22	1	5
	SEM.35	Gaya Isl.	04°37′29.0″	118°46′38.9″	22	2	9
	SEM.36	N Gaya Isl. (back)	04°37′57.6″	118°45′32.3″	27	5	19
	SEM.36B	NW Gaya Isl.	04°38′32.5″	118°44′6.0″	25	3	12
11 Dec	SEM.37	S Boheydulang Isl., outer reef	04°35′00.3″	118°46′39.1″	19	2	11
	SEM.38	Boheydulang Isl., outer reef lagoon	04°34′01.8″	118°45′27.5″	22	5	23
	SEM.39	Tetagan Isl., inner lagoon	04°35′55.4″	118°43′43.2″	21	3	14
	SEM.40	Ribbon reef	04°36′10.0″	118°45′53.6″	18	3	17
12 Dec	SEM.41	Maiga Isl.	04°37′32.2″	118°40′58.0″	29	2	7
	SEM.42	Selakan Isl.	04°34′22.1″	118°43′04.3″	19	2	11
	SEM.43	Sebangkat Isl.	04°33′19.9″	118°39′17.3″	25	5	20
	SEM.43B	Singamata Pancang	04°31′21.0″	118°37′00.7″	21	1	5
13 Dec	SEM.44	Sibuan Isl.	04°39′01.9″	118°39′22.6″	23	4	17
	SEM.45	Church reef 1	04°40′54.9″	118°39′28.4″	26	3	12
	SEM.46	Church reef 2	04°41′10.5″	118°38′56.5″	24	3	13

Table 2 (continued)

Date	Site	Locality name	Latitude (N)	Longitude (E)	Hosts	Gall crabs	%
	SEM.47	Larapan Isl.	04°34′27.5″	118°36′15.0″	25	3	12
15 Dec	SEM.48	Timbun Mata Isl.	04°37′59.6″	118°35′21.6″	23	4	17
	SEM.49	Balusuan Isl.	04°41′07.9″	118°32′29.6″	25	4	16
	SEM.50	Batik Isl.	04°43′09.2″	118°28′22.0″	22	4	18
16 Dec	SEM.51	Tabawan Isl.	04°47′15.6″	118°25′00.8″	24	3	13
	SEM.52	Silumpat Isl.	04°45′58.7″	118°23′25.6″	27	3	11
	SEM.53	Batik Kulambu Isl.	04°42′02.1″	118°23′18.4″	29	1	3
	SEM.54	Bakungan Isl.	04°45′11.1″	118°29′16.0″	22	4	18
17 Dec	SEM.55	Silawa Isl.	04°34′29.8″	118°33′59.6″	21	1	5
	SEM.56	Mata Pahi Isl.	04°34′50.9″	118°32′49.4″	21	2	10
	SEM.57	S Larapan Isl. 2	04°32′51.1″	118°36′31.3″	25	3	12
	SEM.58	Semporna town, mangrove	04°27′35.6″	118°37′33.6″	16	0	0
18 Dec	SEM.59	Sipadan Isl., Baracuda point	04°07′12.0″	118°37′44.9″	17	0	0
	SEM.60	Sipadan Isl., Hanging gardens	04°06′45.3″	118°37′29.3″	13	1	8

Distribution patterns

So far little information is available on the distribution patterns of coral-associated organisms (see e.g. Gittenberger and Hoeksema 2013), in particular gall crabs. The present results show that localities with relatively high occupancy rates are distributed quite evenly over the research area, but that low occurrence rates are only found in the southern part of the research area. Apart from having few or no gall crab-inhabited mushroom coral species, those sites also differed in fungiid species composition. Some sites with low occurrence numbers can be related to oceanic conditions (SEM.59–60). Other sites were heavily damaged by blast fishing (SEM.15) or affected by high nutrient impact (SEM.58) (Waheed and Hoeksema 2013). Natural and anthropogenic stress have negative effects on coral assemblages and hence on their associated cryptofauna (Sebens 1994; van der Meij et al. 2010).

Near-shore sites show lower numbers of inhabited corals compared to offshore sites (Fig. 1). Cross-shelf distribution data of gall crab-inhabited mushroom corals in the Spermonde Archipelago (SW Sulawesi) show a similar presence/absence pattern, with the near-shore reefs having the lowest occurrence rates (0–6 % of the available host species) (van der Meij et al., in preparation). In the Spermonde, where mushroom coral distributions have been studied extensively (Hoeksema 2012), no clear differences in occurrence rates between the mid-shelf and outer-shelf reefs can be discerned (van der Meij et al., in preparation). Near-shore reefs can have a higher sediment load, especially close to river outlets (van der Meij et al. 2010; Erftemeijer et al. 2012). Kramarsky-Winter et al. (1995) mention that no crab-inhabited fungiids were found in sandy areas, and relate this to the fact that sediments may fill the crab's burrow, hence smothering the crab.

Concluding remarks

Previous research involving gall crab occurrence data was conducted in the western Atlantic (Mexican Caribbean and Brazil) and the Red Sea, making the present study the first in the central Indo-Pacific. The number of inhabited fungiid species recorded per locality showed occurrence rates from 0 to 25 %. In general, sites with higher infestation rates had higher numbers of host species. The distribution patterns of inhabited host species (at the different sites) show that there is little difference (chi-squared test, $df=1$, $p>0.05$) between the more sheltered reefs in the northern section of the study area and the more exposed reefs in the south, where all the low crab occurrences were recorded. The majority of these sites have low fungiid species richness and a different fungiid species composition (Waheed and Hoeksema 2013).

Cryptochirids are diminutive crabs that may occur in high densities but are usually overlooked on coral reefs (Hoeksema and van der Meij 2013). A little over 85 % (53 out of 62) of the reef sites around the Semporna peninsula harbour mushroom corals inhabited by gall crabs. Non-inhabited sites can be related to disturbances. Future studies will tell more about their diversity and the evolution of their host specificity (van der Meij, in preparation.).

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References

Bos AR (2012) Fishes (Gobiidae and Labridae) associated with the mushroom coral *Heliofungia actiniformis* (Scleractinia: Fungiidae) in the Philippines. Coral Reefs 31:133

Carricart-Ganivet JP, Carrera-Parra LF, Quan-Young LI, García-Madrigal MS (2004) Ecological note on *Troglocarcinus corallicola* (Brachyura: Cryptochiridae) living in symbiosis with *Manicina areolata* (Cnidaria: Scleractinia) in the Mexican Caribbean. Coral Reefs 23:215–217

Clarke KR, Gorley RN (2006) PRIMER v6: user manual/tutorial. PRIMER-E, Plymouth

Erftemeijer PLA, Riegl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: a review. Mar Pollut Bull 64:1737–1765

Fize A, Serène R (1957) Les hapalocarcinides du Viet-Nam. Mém Inst Océanogr Nhatrang 10:1–202

Gittenberger A, Hoeksema BW (2013) Habitat preferences of coral-associated wentletrap snails (Gastropoda: Epitoniidae). Contrib Zool (in press)

Gittenberger A, Reijnen BT, Hoeksema BW (2011) A molecularly based phylogeny reconstruction of mushroom corals (Scleractinia: Fungiidae) with taxonomic consequences and evolutionary implications for life history traits. Contrib Zool 80:107–132

Hoeksema BW (1989) Taxonomy, phylogeny and biogeography of mushroom corals (Scleractinia: Fungiidae). Zool Verh 254:1–295

Hoeksema BW (1991a) Control of bleaching in mushroom coral populations (Scleractinia: Fungiidae) in the Java Sea: stress tolerance and interference by life history strategy. Mar Ecol Prog Ser 74:225–237

Hoeksema BW (1991b) Evolution of body size in mushroom corals (Scleractinia: Fungiidae) and its ecomorphological consequences. Neth J Zool 41:122–139

Hoeksema BW (2007) Delineation of the Indo-Malayan centre of maximum marine biodiversity: the Coral Triangle. In: Renema W (ed) Biogeography, time and place: distributions, barriers and islands. Springer, Dordrecht, pp 117–178

Hoeksema BW (2012) Distribution patterns of mushroom corals (Scleractinia: Fungiidae) across the Spermonde Shelf, South Sulawesi. Raffles Bull Zool 60:183–212

Hoeksema BW, Koh EGL (2009) Depauperation of the mushroom coral fauna (Fungiidae) of Singapore (1860 s–2006) in changing reef conditions. Raffles Bull Zool Suppl 22:91–101

Hoeksema BW, Moka W (1989) Species assemblages and ecomorph variation of mushroom corals (Scleractinia: Fungiidae) related to reef habitats in the Flores Sea. Neth J Sea Res 23:149–160

Hoeksema BW, van der Meij SET (2013) Gall crab city: an aggregation of endosymbiotic crabs inhabiting a colossal colony of *Pavona clavus*. Coral Reefs. doi:10.1007/s00338-012-0954-4

Hoeksema BW, van der Meij SET, Fransen CHJM (2012) The mushroom coral as a habitat. J Mar Biol Assoc UK 92:647–663

Johnsson R, Neves E, Franco GMO, da Silveira FL (2006) The association of two gall crabs (Brachyura: Cryptochiridae) with the reef-building coral *Siderastrea stellata* Verrill, 1868. Hydrobiologia 559:379–384

Kramarsky-Winter E, Galil BS, Loya Y (1995) Biology and ecology of the cryptic cryptochirid crab *Fungicola fagei* and its free-living coral host *Fungia granulosa*. Israel J Zool 41:94–95

Kropp RK (1990) Revision of the genera of gall crabs (Crustacea: Cryptochiridae) occurring in the Pacific Ocean. Pac Sci 44:417–448

Kropp RK, Manning RB (1987) The Atlantic gall crabs, family cryptochiridae (Crustacea: Decapoda: Brachyura). Smithson Contrib Zool 462:1–21

Oigman-Pszczol SS, Creed JC (2006) Distribution and abundance of fauna on living tissues of two Brazilian hermatypic corals (*Mussismilia hispida* (Verril, 1902) and *Siderastrea stellata* Verril, 1868). Hydrobiologia 563:143–154

Sebens KP (1994) Biodiversity of coral-reefs: what are we losing and why? Am Zool 34:115–133

Simon-Blecher N, Achituv Y (1997) Relationship between the coral pit crab *Cryptochirus coralliodytes* Heller and its host coral. J Exp Mar Biol Ecol 215:93–102

Stella JS, Jones GP, Pratchett MS (2010) Variation in the structure of epifaunal invertebrate assemblages among coral hosts. Coral Reefs 29:957–973

Stella JS, Pratchett MS, Hutchings PA, Jones GP (2011) Coral-associated invertebrates: diversity, ecological importance and vulnerability to disturbance. Oceanogr Mar Biol Annu Rev 49:43–104

van der Meij SET (2012) Host preferences, colour patterns and distribution records of *Pseudocryptochirus viridis* Hiro, 1938 (Decapoda, Cryptochiridae). Crustaceana 85:769–777

van der Meij SET, Suharsono, Hoeksema BW (2010) Long-term changes in coral assemblages under natural and anthropogenic stress in Jakarta Bay (1920–2005). Mar Pollut Bull 60:1442–1454

Waheed Z, Hoeksema BW (2013) A tale of two winds: species richness patterns of reef corals around the Semporna peninsula, Malaysia. Mar Biodivers. doi:10.1007/s12526-012-0130-7